Large-scale structures in (moist) atmospheric convection

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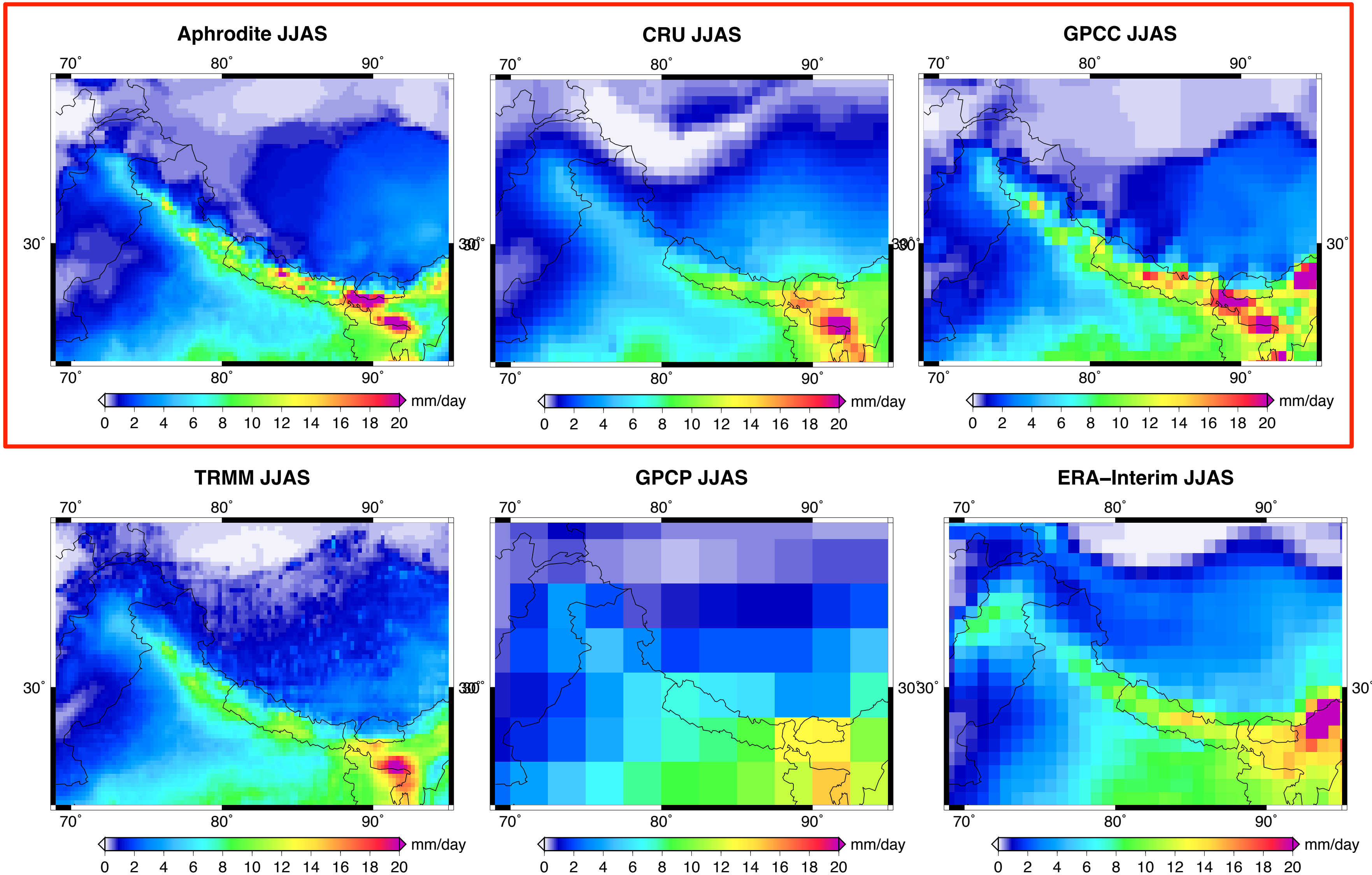
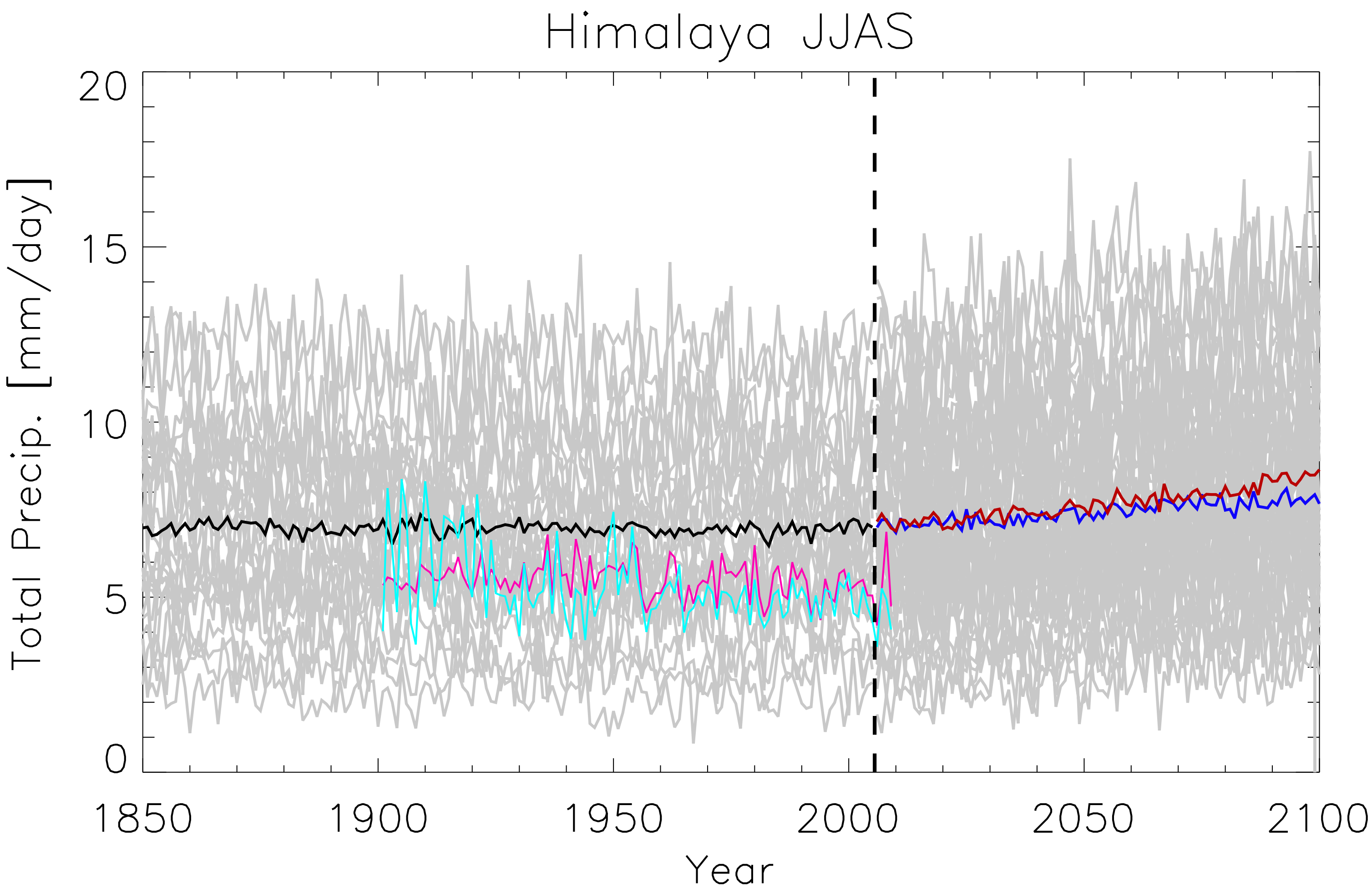
Precipitation is a difficult variable to measure: 30-y climatology for HKKH from datasets



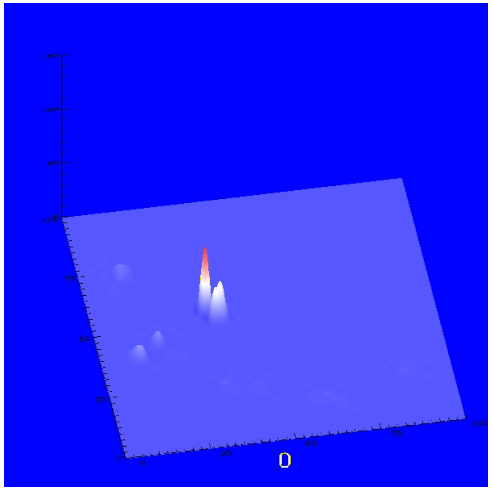
Palazzi, von Hardenberg, Provenzale, JGR 2013

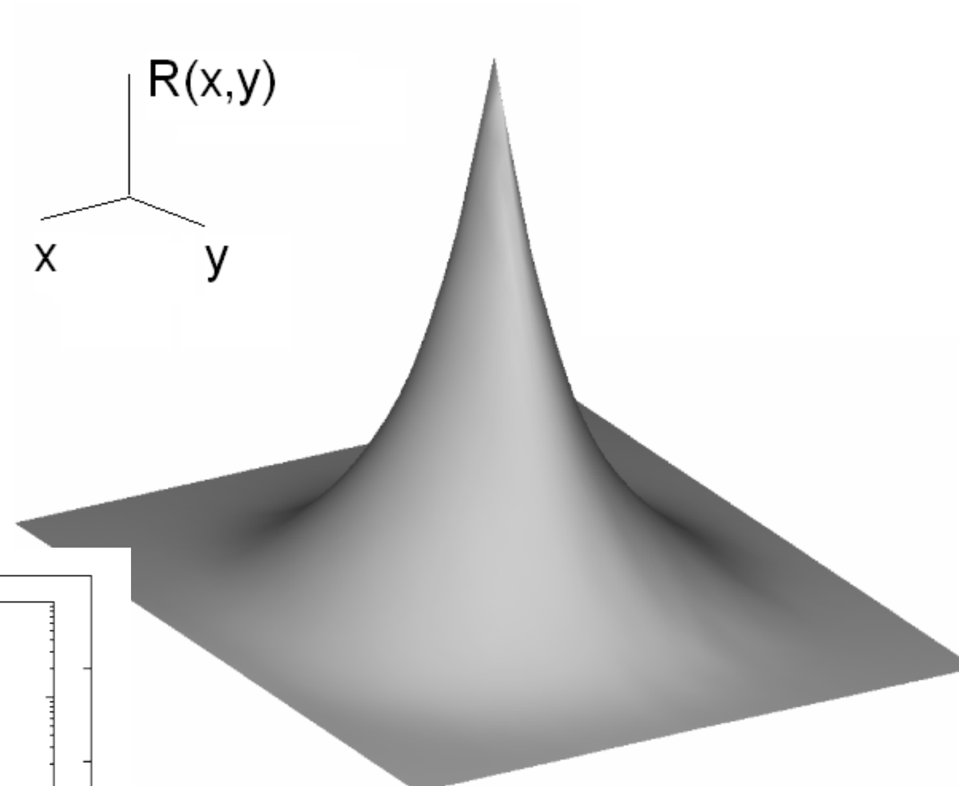
… and even more difficult to predict: CMIP5 models over the Himalaya

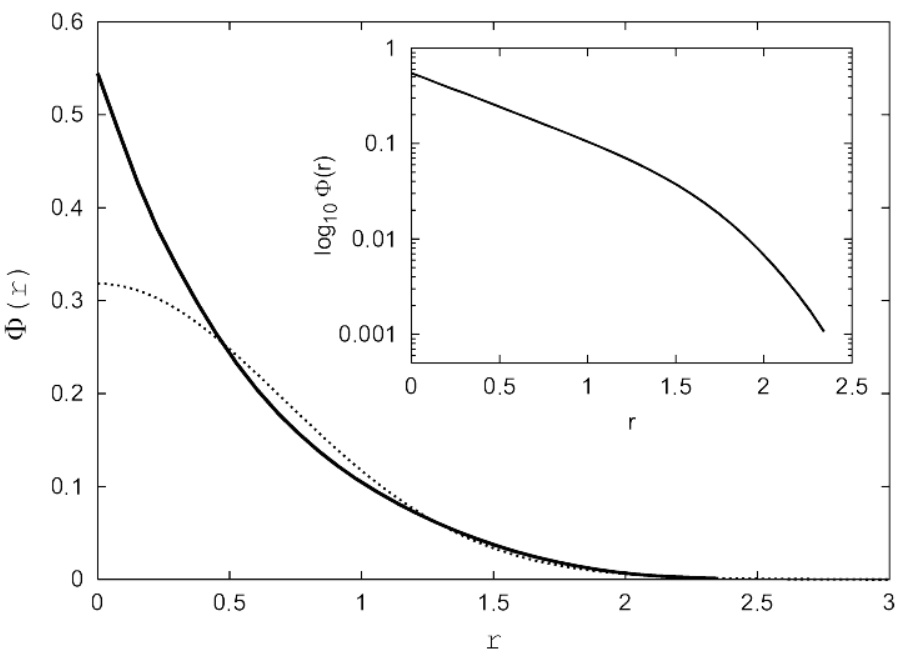


Palazzi, von Hardenberg, Provenzale, *in preparation* 2014

One issue: intense localized convective rain cells

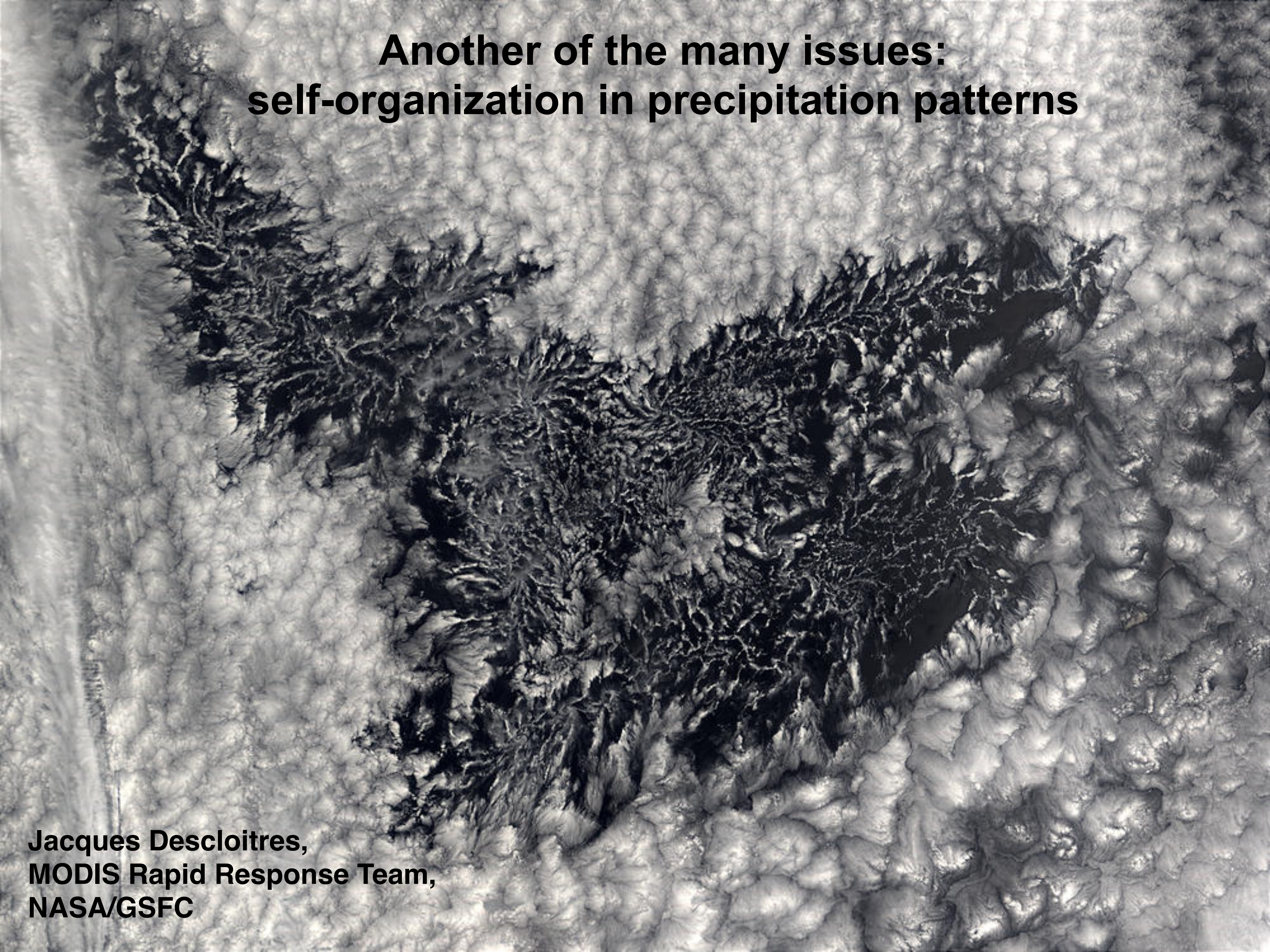






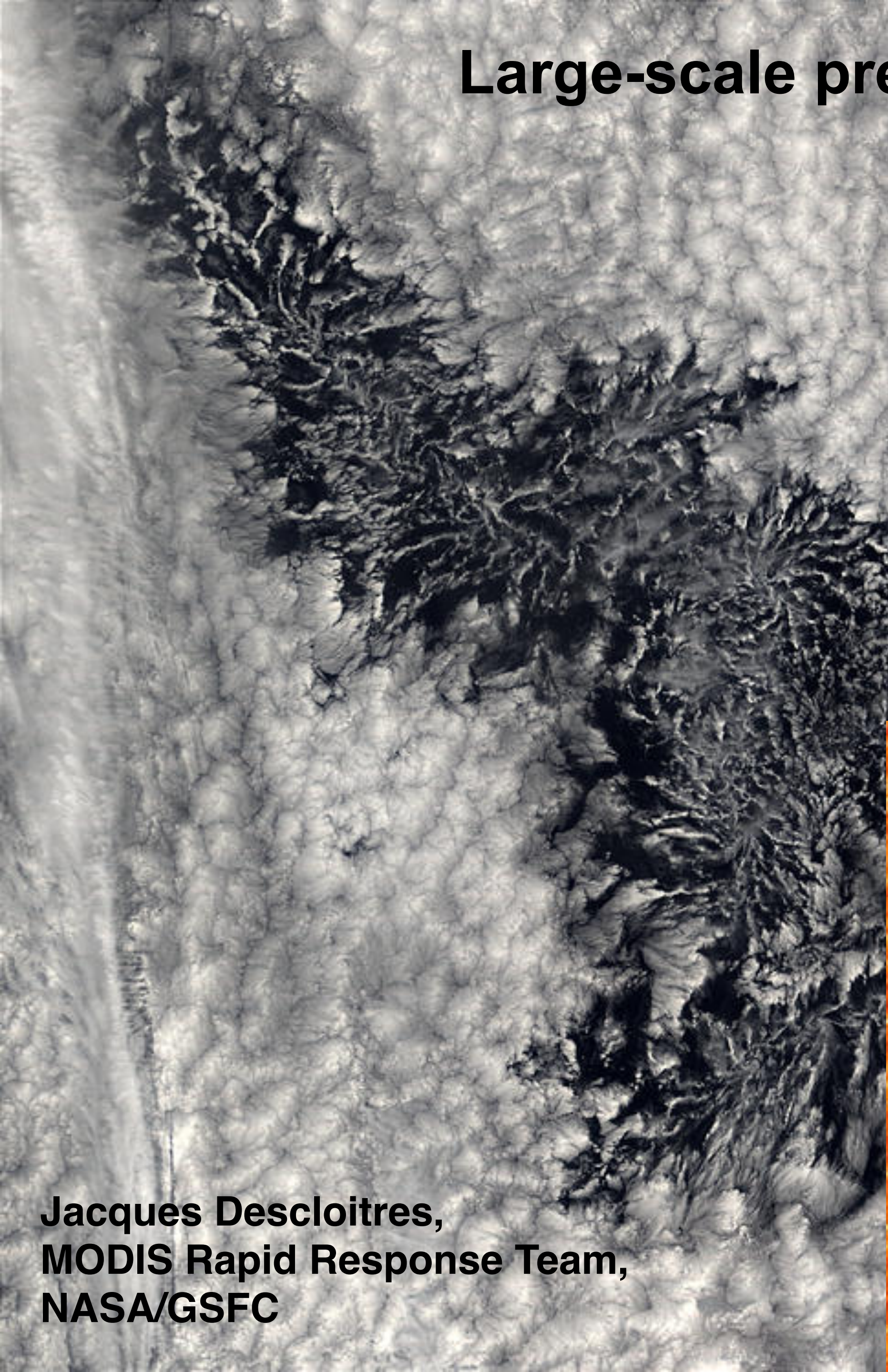
TOGA-COARE data
von Hardenberg et al, GRL 2003

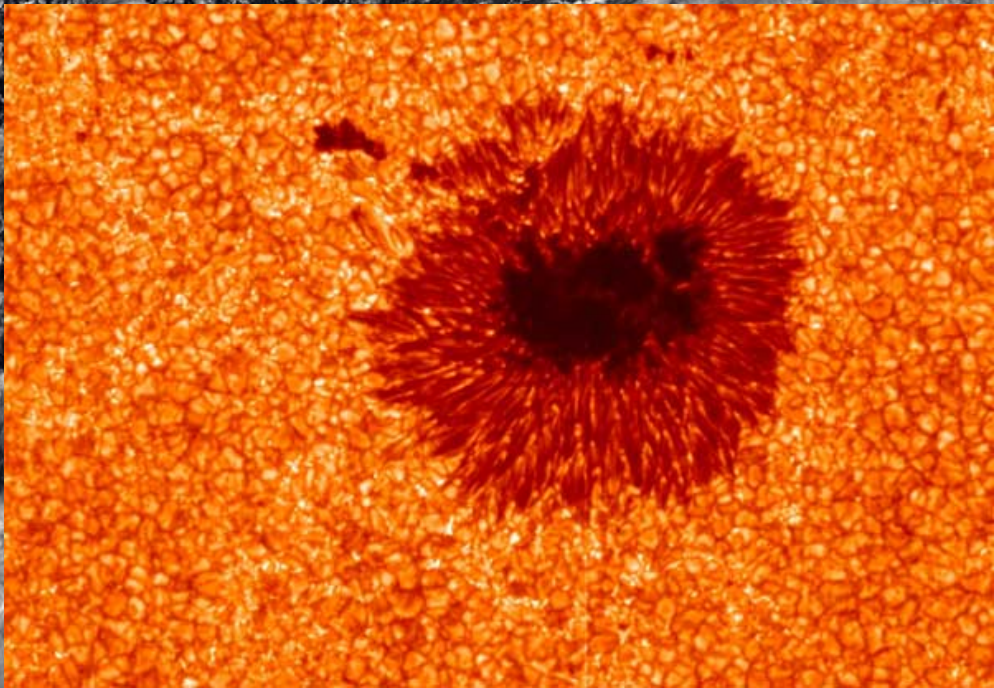
Another of the many issues: self-organization in precipitation patterns



Jacques Descloitres,
MODIS Rapid Response Team,
NASA/GSFC

Large-scale precipitation patterns





Jacques Descloitres,
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Formation of large-scale order in turbulent RB convection

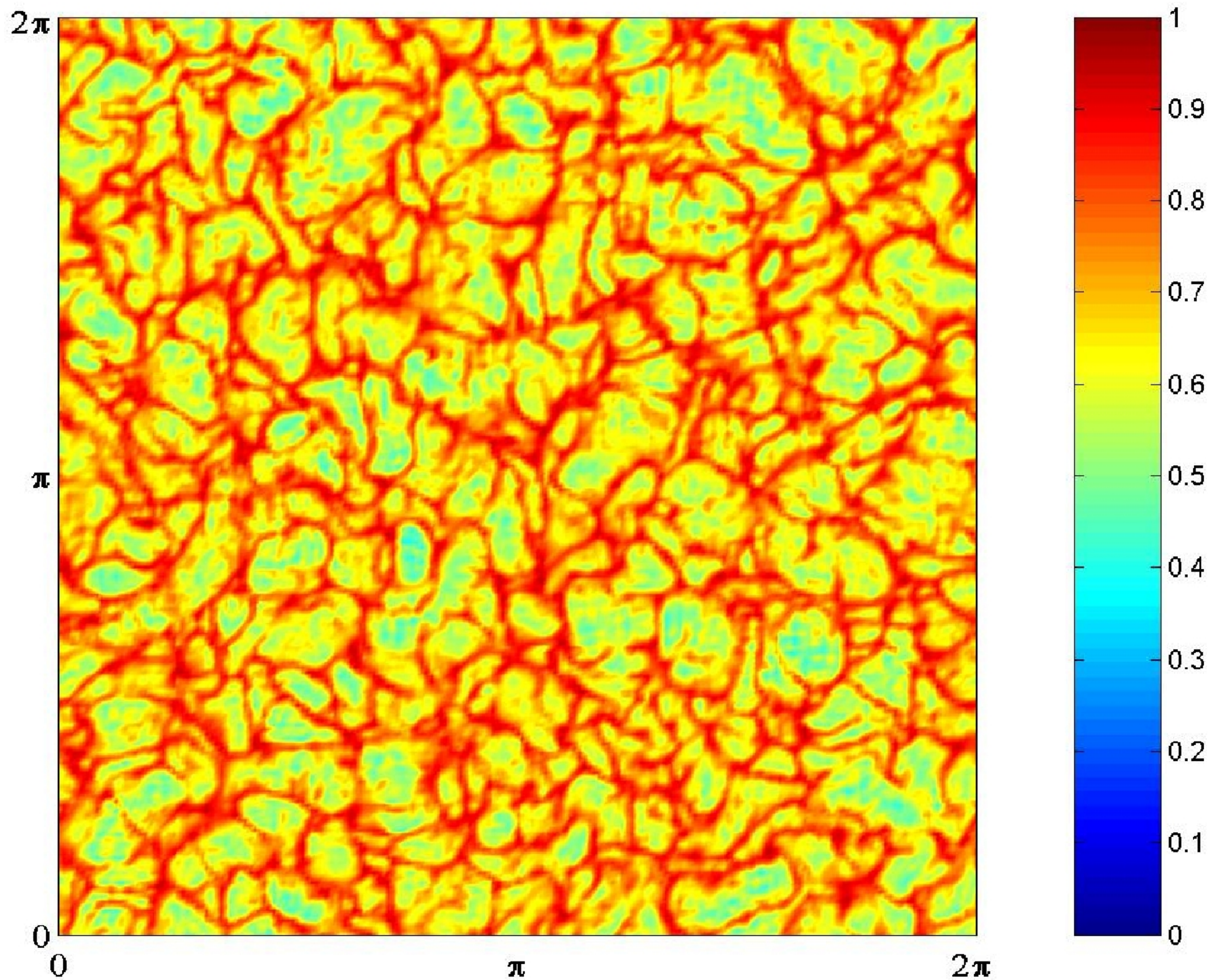
Large-scale wind and generation of mean shear
(rectification process, k=0):
Krishnamurti and Howard (1981)
Howard and Krishnamurti (1986)
Massaguer, Spiegel and Zahn (1992)

Large-scale wind leads to plume clustering:
Heslot et al (1987)
Kadanoff (2001)

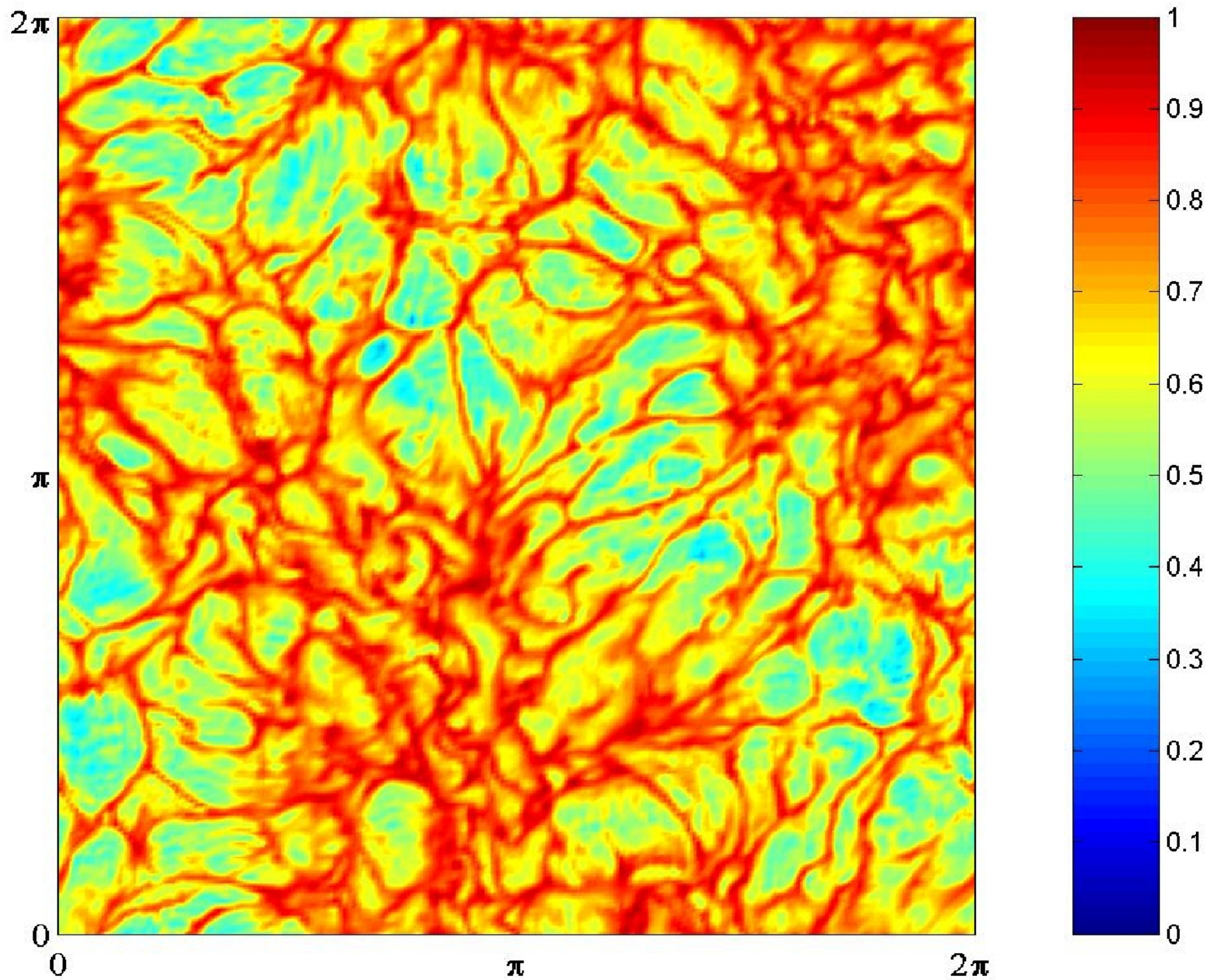
Instability of the long-wave modes in
turbulent convection:
Elperin et al (2003)

Numerical simulation of 3D RB convection with periodic b.c.:
No k=0 mode
Hartlep, Tilgner and Busse (2003)
Parodi, von Hardenberg, Passoni, Provenzale, Spiegel, *PRL* (2003)

Coarsening of the plume pattern (Ra=10^7):



Coarsening of the plume pattern ($Ra=10^7$):



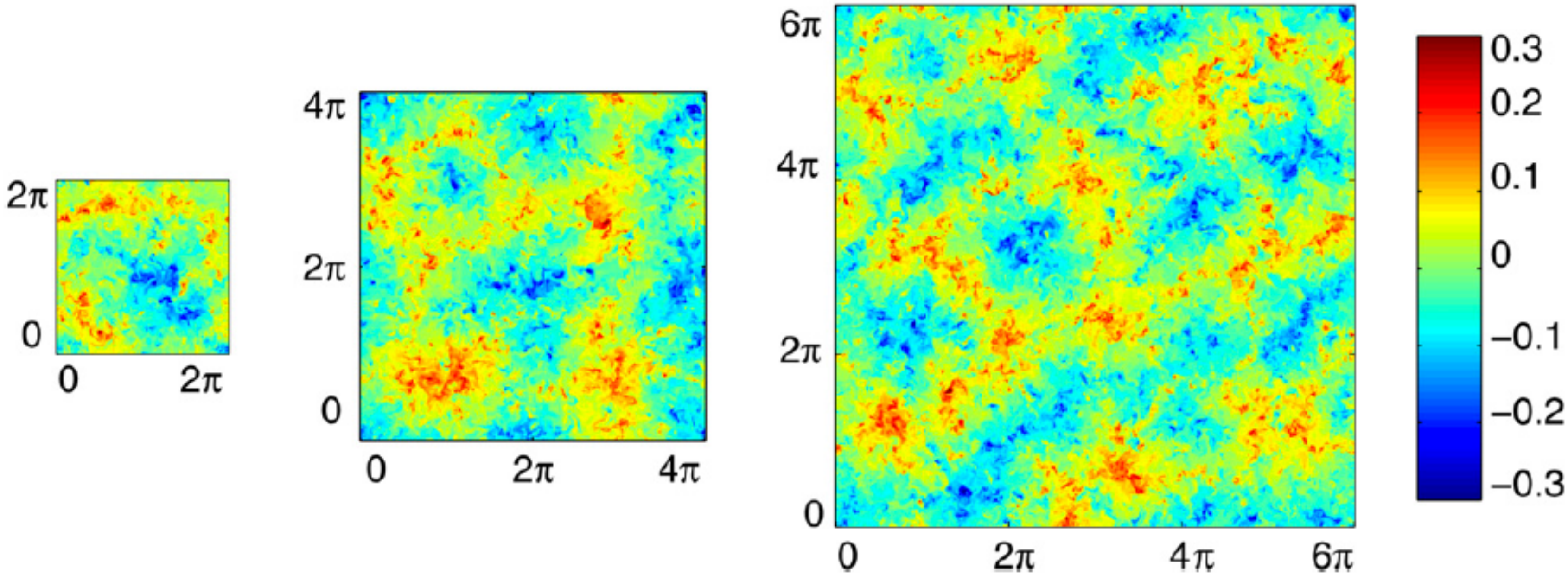
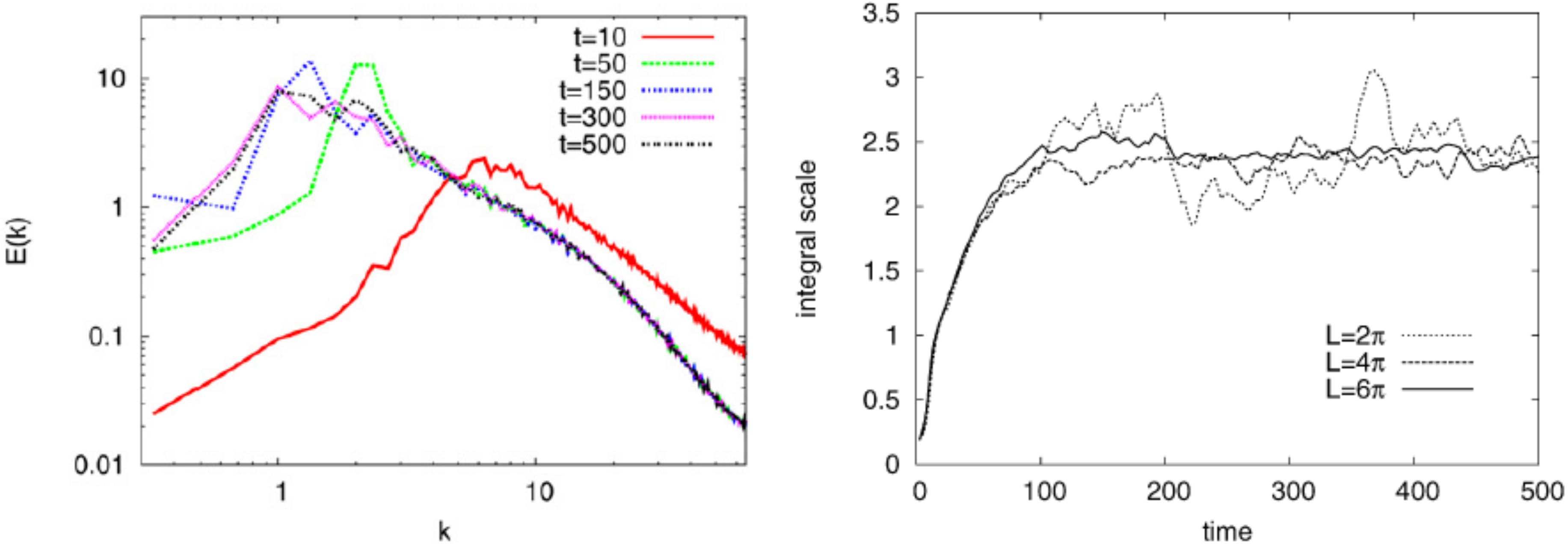
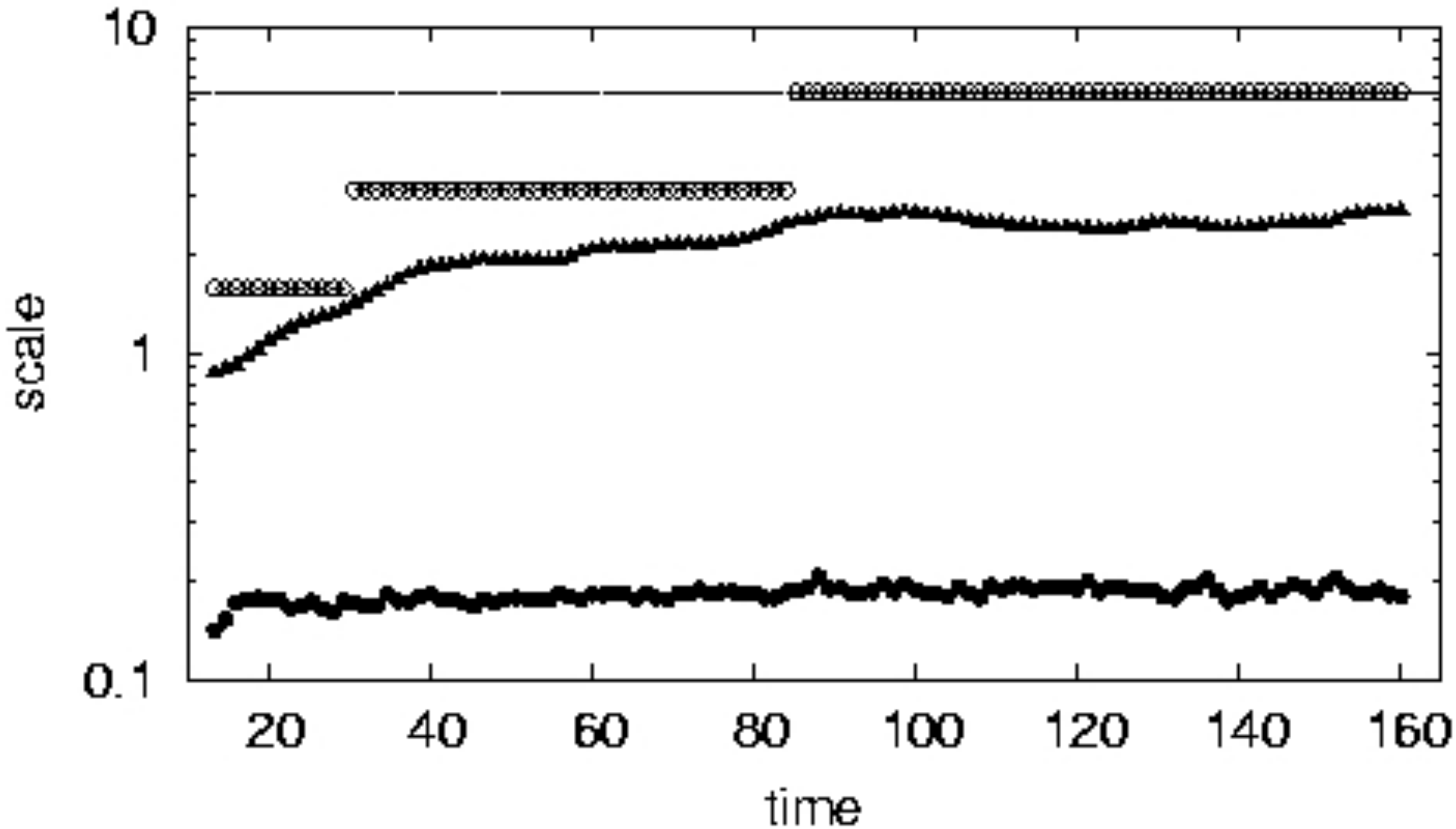


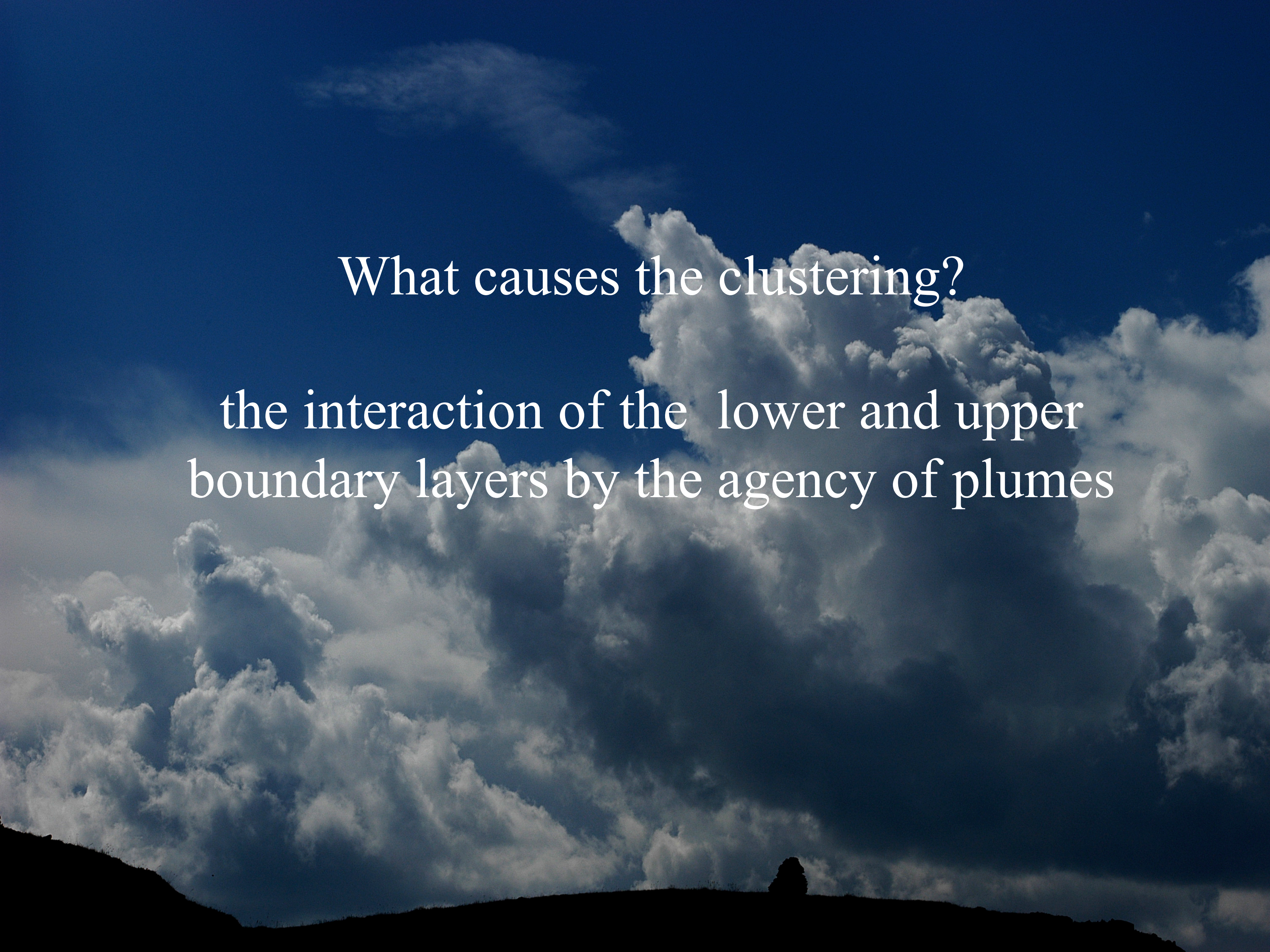
Fig. 2. Horizontal sections of the temperature fields for $R = 10^7$ at $t = 500$, $z = \frac{1}{2}$, $L = 2\pi$ (left), $L = 4\pi$ (center) and $L = 6\pi$ (right).



The coarsening is due to clustering of convective plumes:



Parodi et al, PRL 2004, von Hardenberg Phys. Lett. A 2008


What causes the clustering?
the interaction of the lower and upper boundary layers by the agency of plumes

Penetrative convection with constant "radiative" cooling and lapse rate

$$\frac{D\mathbf{u}}{Dt} = -\nabla p + T\hat{\mathbf{z}} + \frac{\tau_c}{\tau_e}\nabla^2\mathbf{u},$$

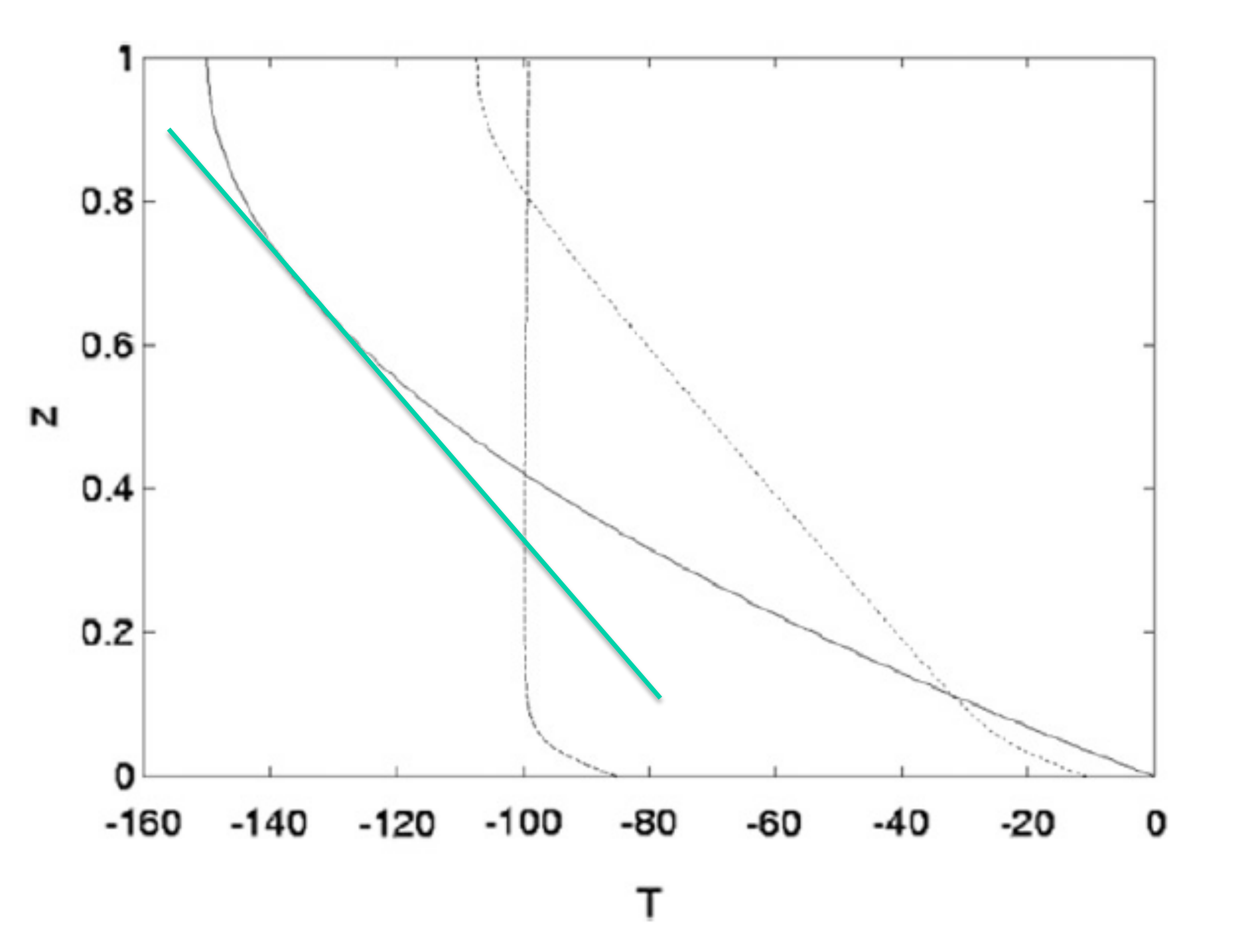
$$\nabla \cdot \mathbf{u} = 0,$$

$$\frac{DT}{Dt} + \gamma w = -\frac{\tau_c}{\tau_{rad}} + \frac{\tau_c}{\tau_e}\nabla^2 T.$$

$$\tau_c = (\alpha T_0 g/H)^{-1/2} \qquad \tau_e = H^2/K_e$$

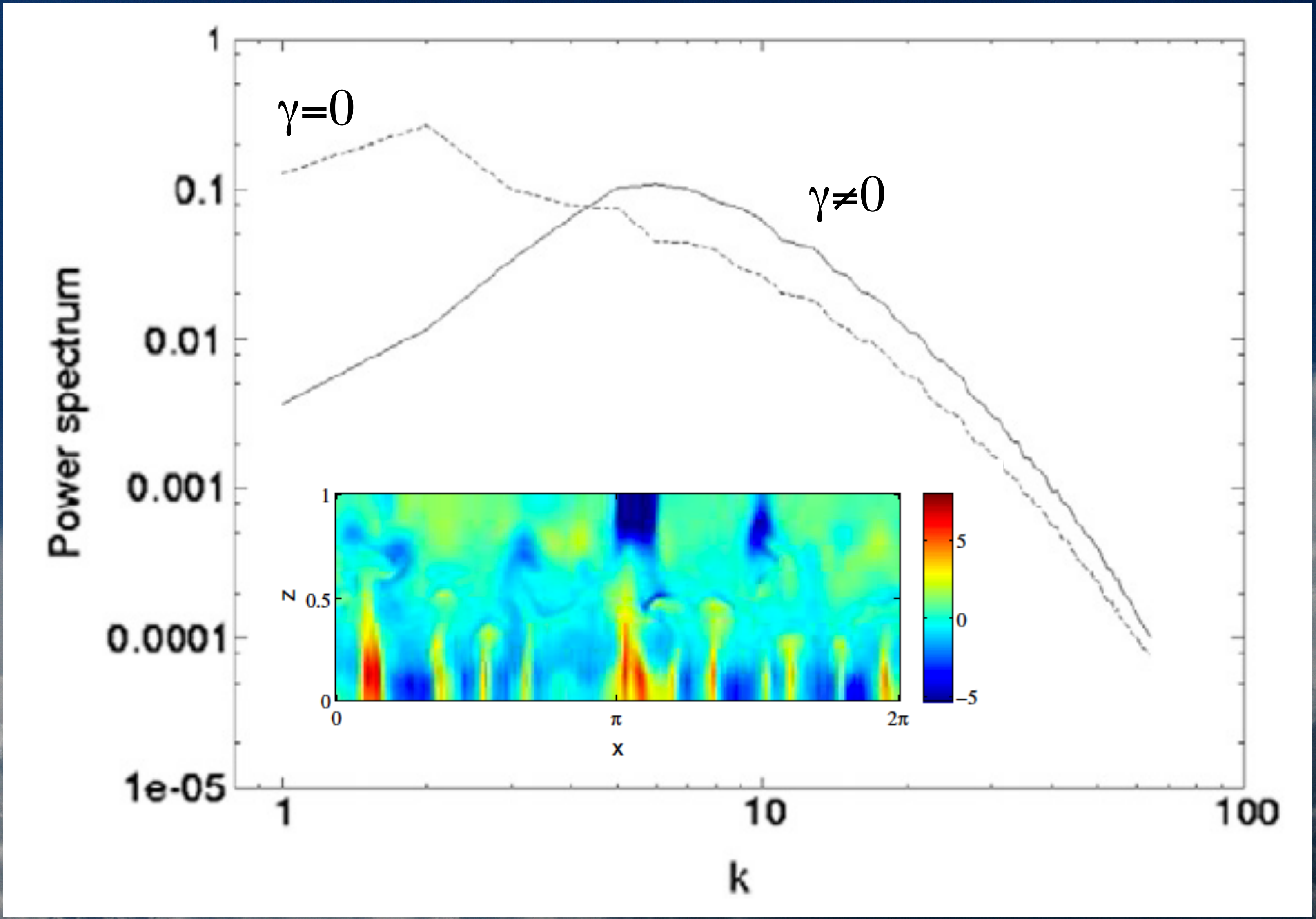
$$\tau_{rad} = \rho c_p T_0 / J_0 \qquad \gamma = \Gamma H / T_0$$

$$\tilde{D}\tilde{T}/\tilde{D}\tilde{t} + \Gamma\tilde{w} = -J_0/(\rho c_p) + K_e \tilde{\nabla}^2 \tilde{T}.$$



Internally cooled convection: A fillip for Philip

M. Berlengiero [a], K.A. Emanuel [b], J. von Hardenberg [a], A. Provenzale [a,*], E.A. Spiegel [c]



This simple model of penetrative non-precipitating convection does not lead to large-scale structures

Large-scale patterns in moist precipitating convection: A long history of investigations

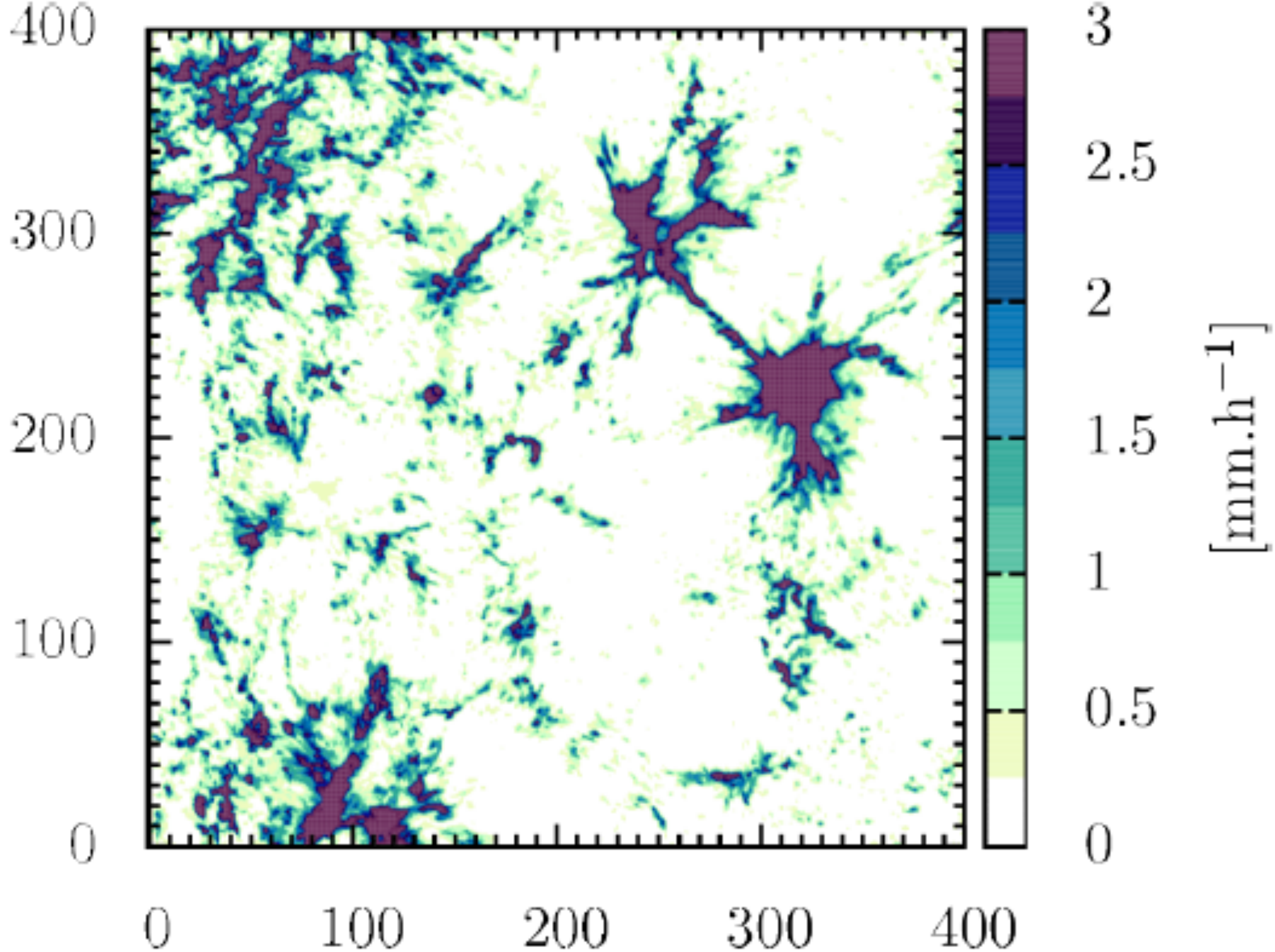
Feingold et al. 2010
Precipitation-generated oscillations in open cellular cloud fields
(role of cold pools)

Bretherton et al. 2005
An Energy-Balance Analysis of Deep Convective Self-Aggregation above Uniform SST

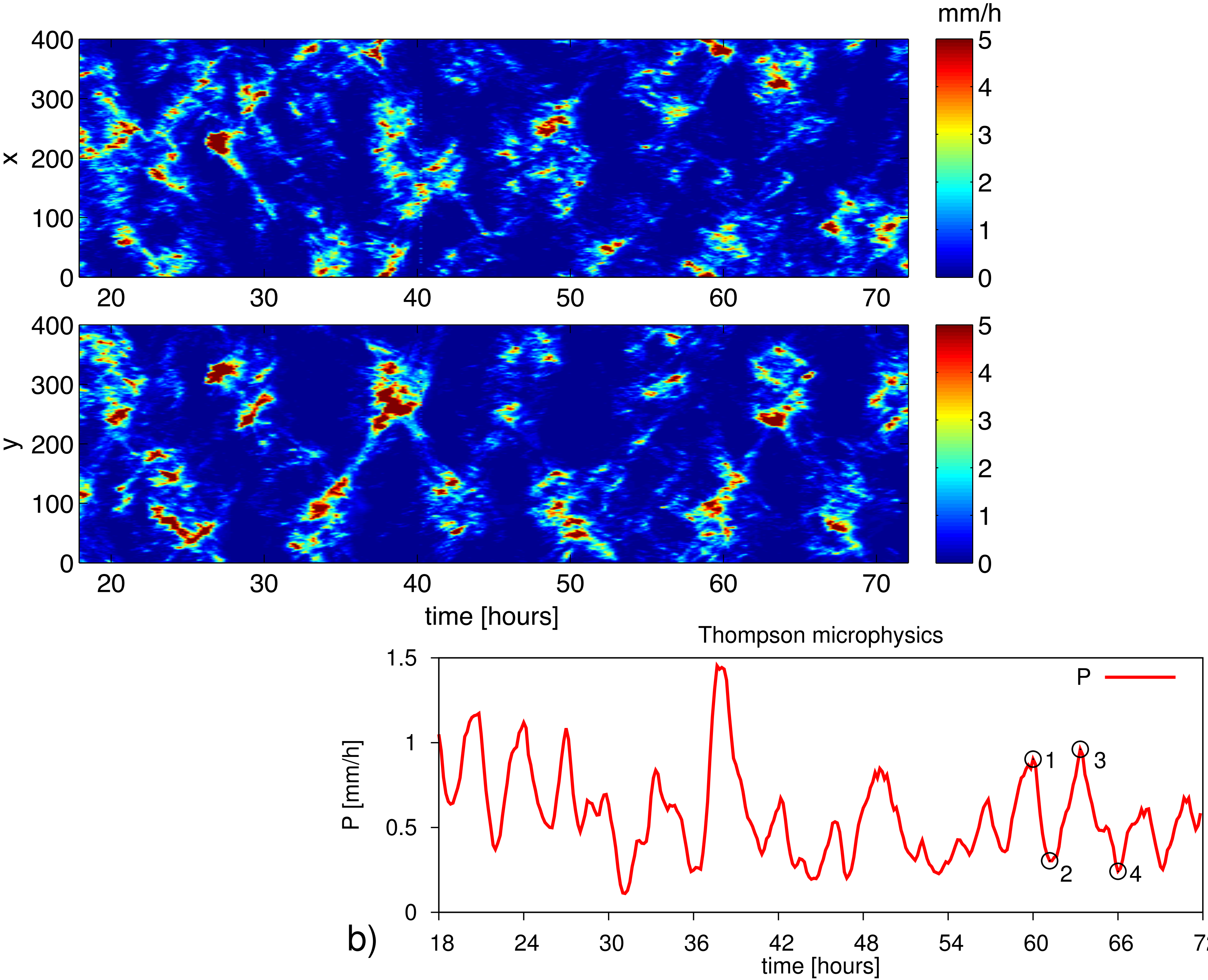
WRF model, periodic lateral BC
homogeneous lower boundary

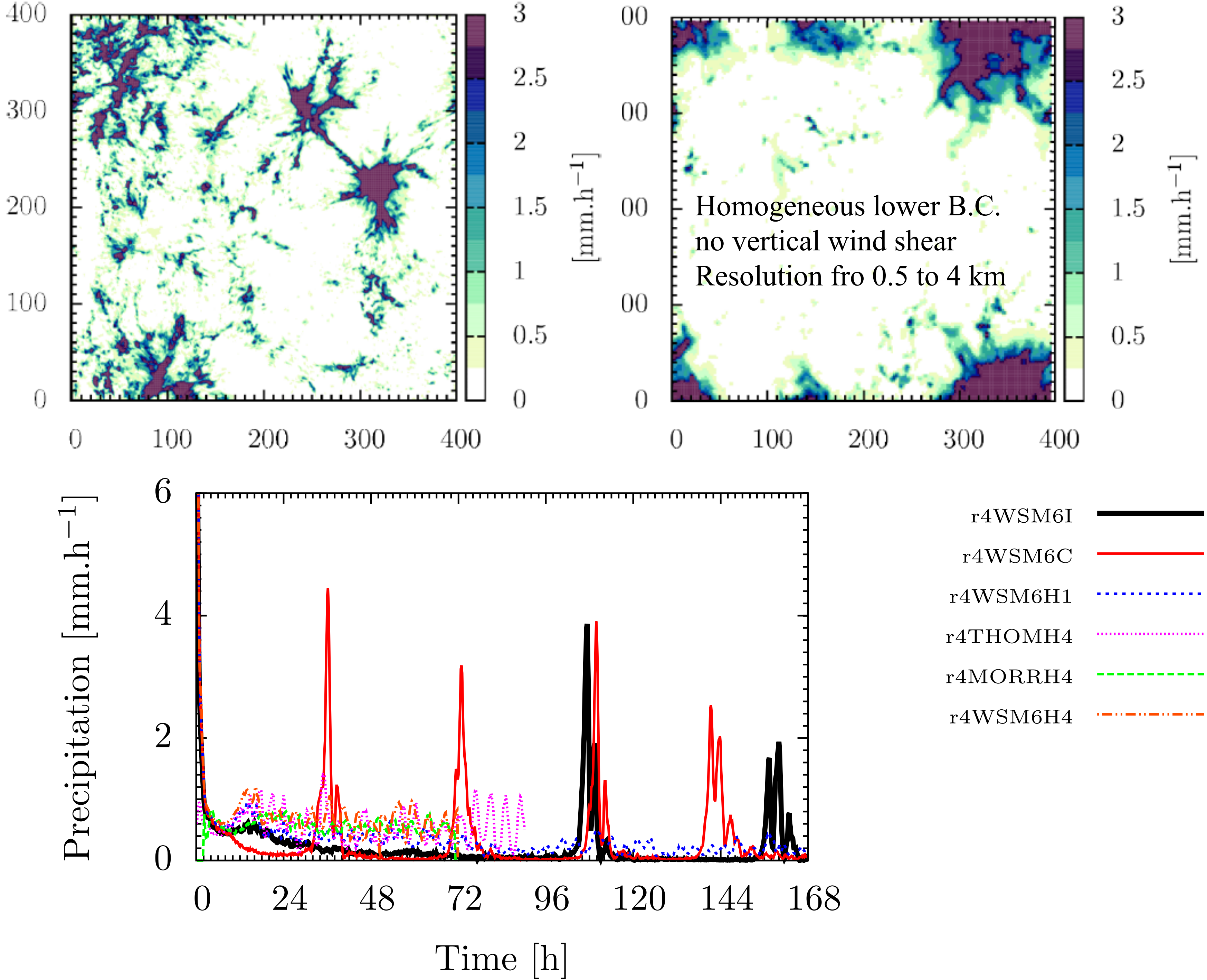
WSM6 microphysics
Thomson microphysics
Morrison microphysics
Δx= 0.5 - 2 km ; L = 400 km ; H = 20 km
60 vertical levels in hydrostatic coordinates

Constant radiative cooling -4 K/day
Constant radiative cooling -1 K/day
Interactive radiation
One more choice

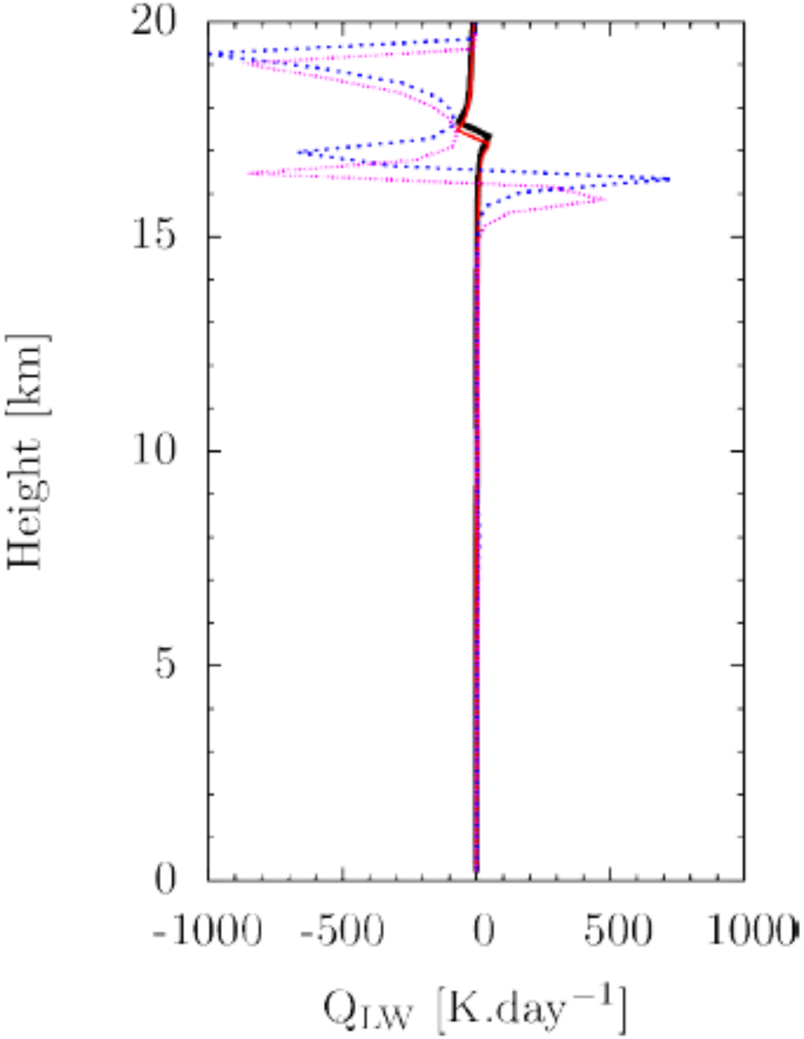


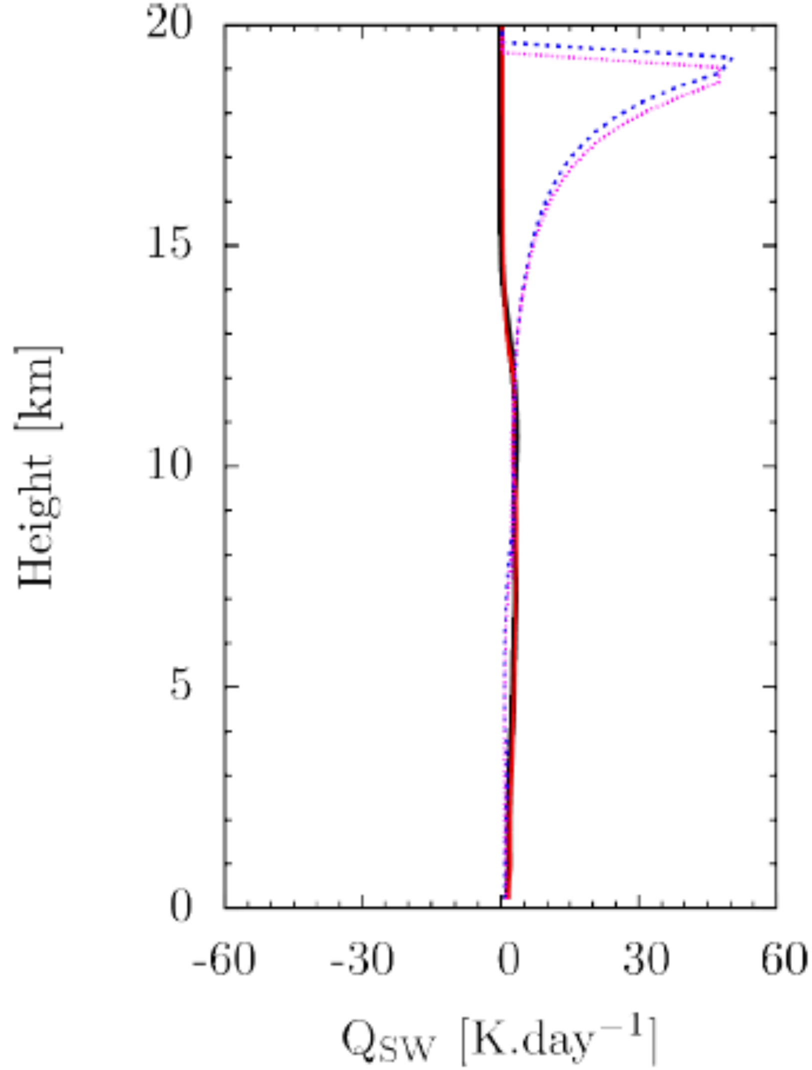
(c) r4THOMH4


mm/h
x
y
time [hours]
Thompson microphysics
P [mm/h]
P
1
2
3
4
b)
time [hours]

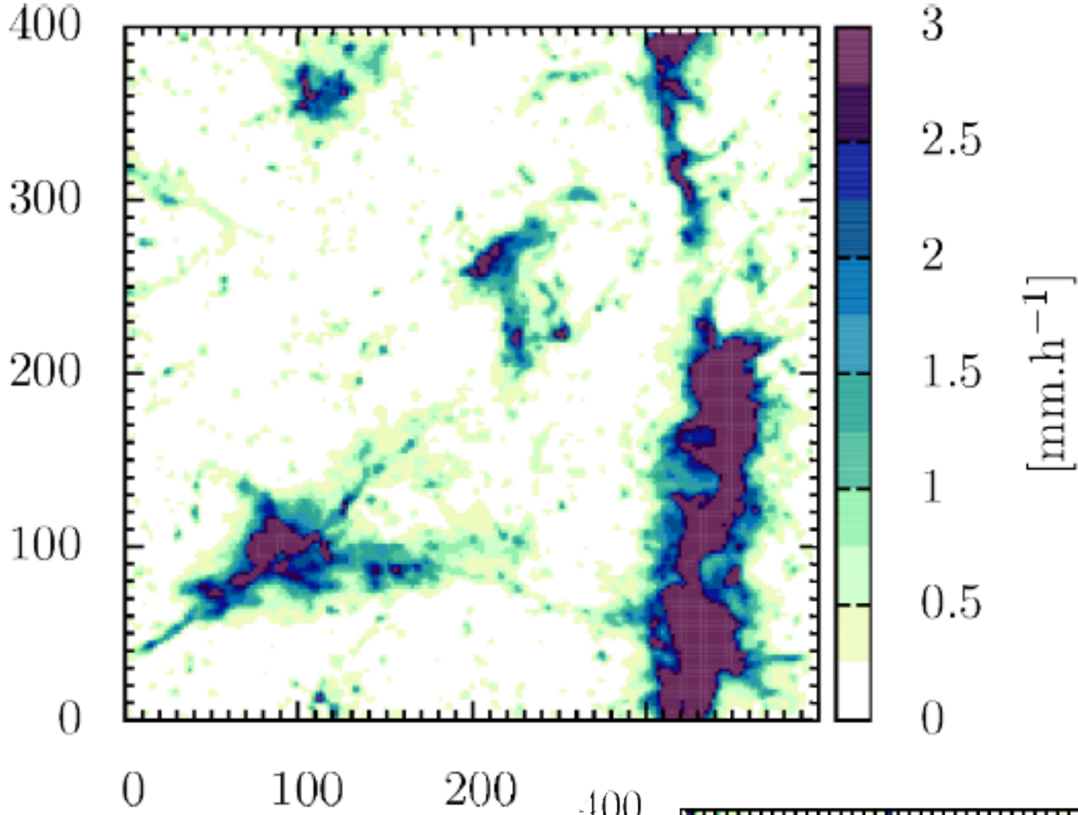


[mm.h^{-1}]
Homogeneous lower B.C.
no vertical wind shear
Resolution fro 0.5 to 4 km
Precipitation [mm.h^{-1}]
Time [h]
r4WSM6I
r4WSM6C
r4WSM6H1
r4THOMH4
r4MORRH4
r4WSM6H4

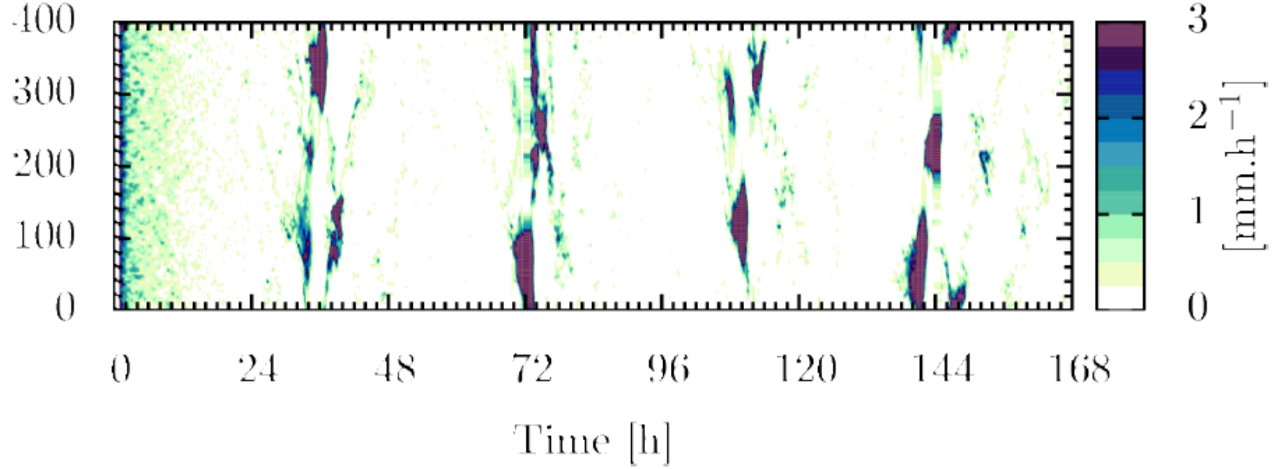




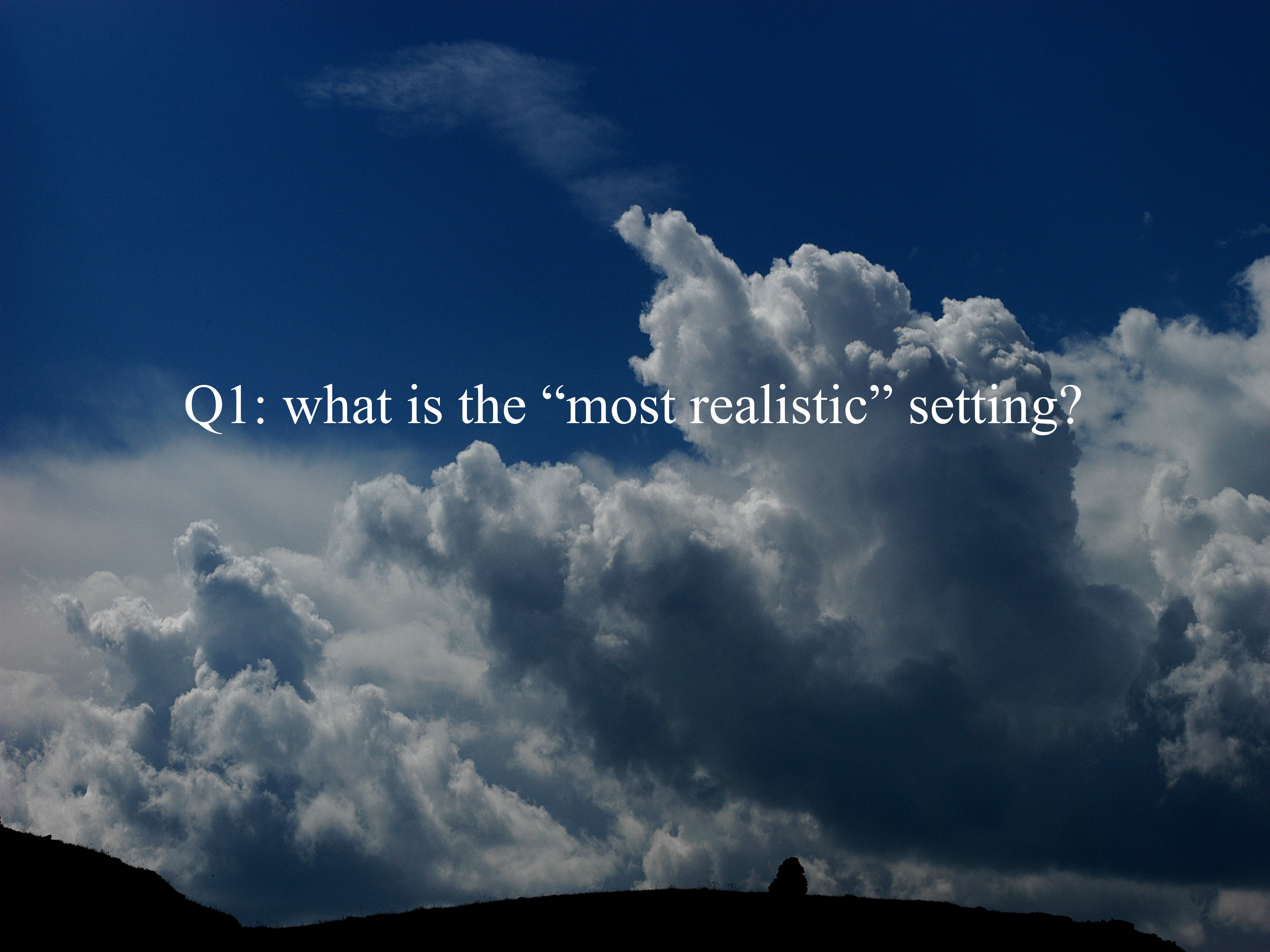
Long- and short-wave cooling/heating

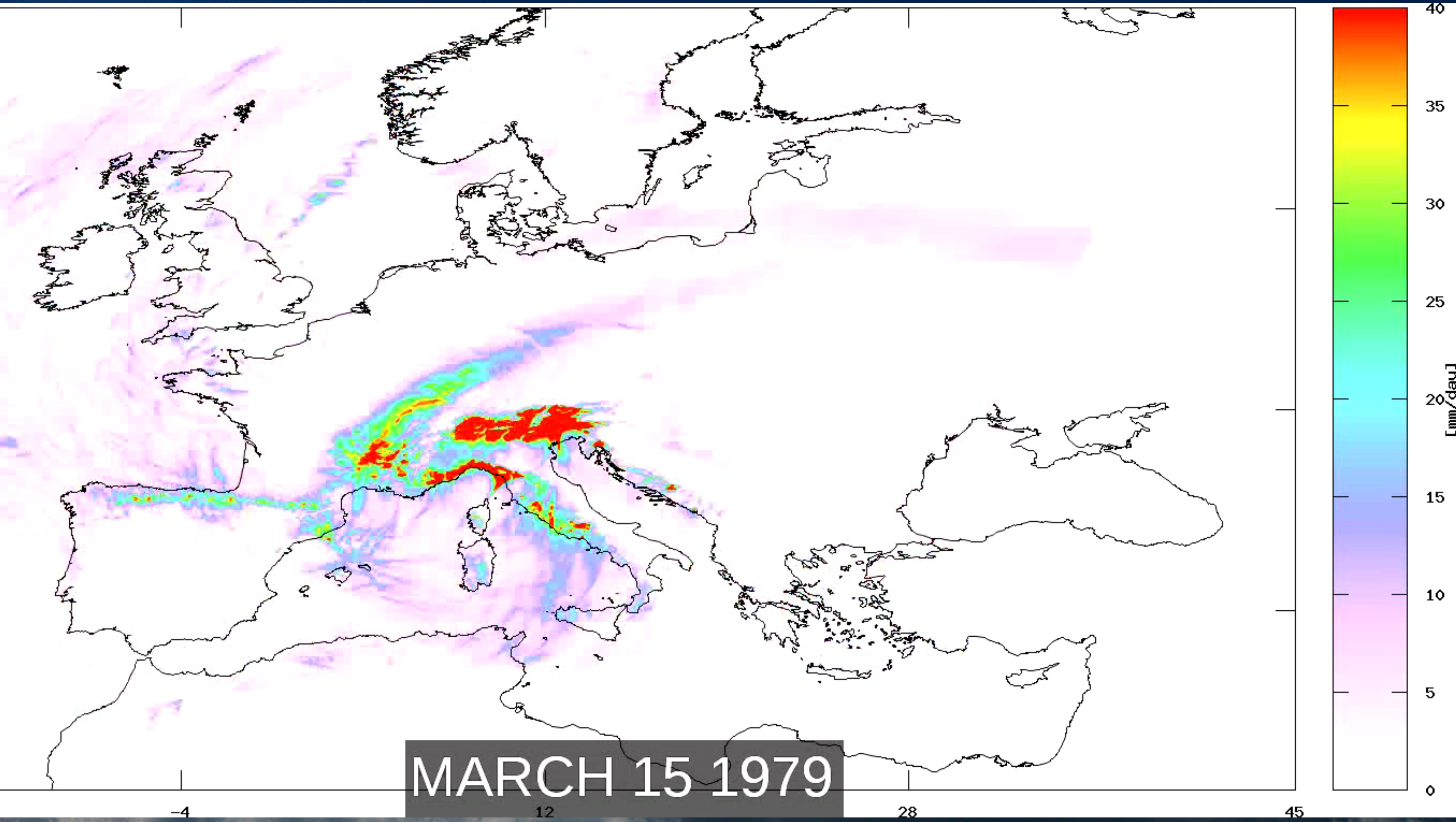


Turn off radiation-convection interactions



Imposed cooling/heating profile


Q1: what is the "most realistic" setting?



WRF at 4 km resolution over Europe, nested into ERA-Interim, 30 y of simulation

Q2: what is the tradeoff
between convective istabilities
and imposed ordering fields?

Role of inhomogeneities in the lower b.c.

Role of lateral boundary conditions:
tradeoff between the instabilities of the nested model
and the ordering effect of the large-scale circulation


Thanks for your attention